Chapter 17

Lecture Outline*

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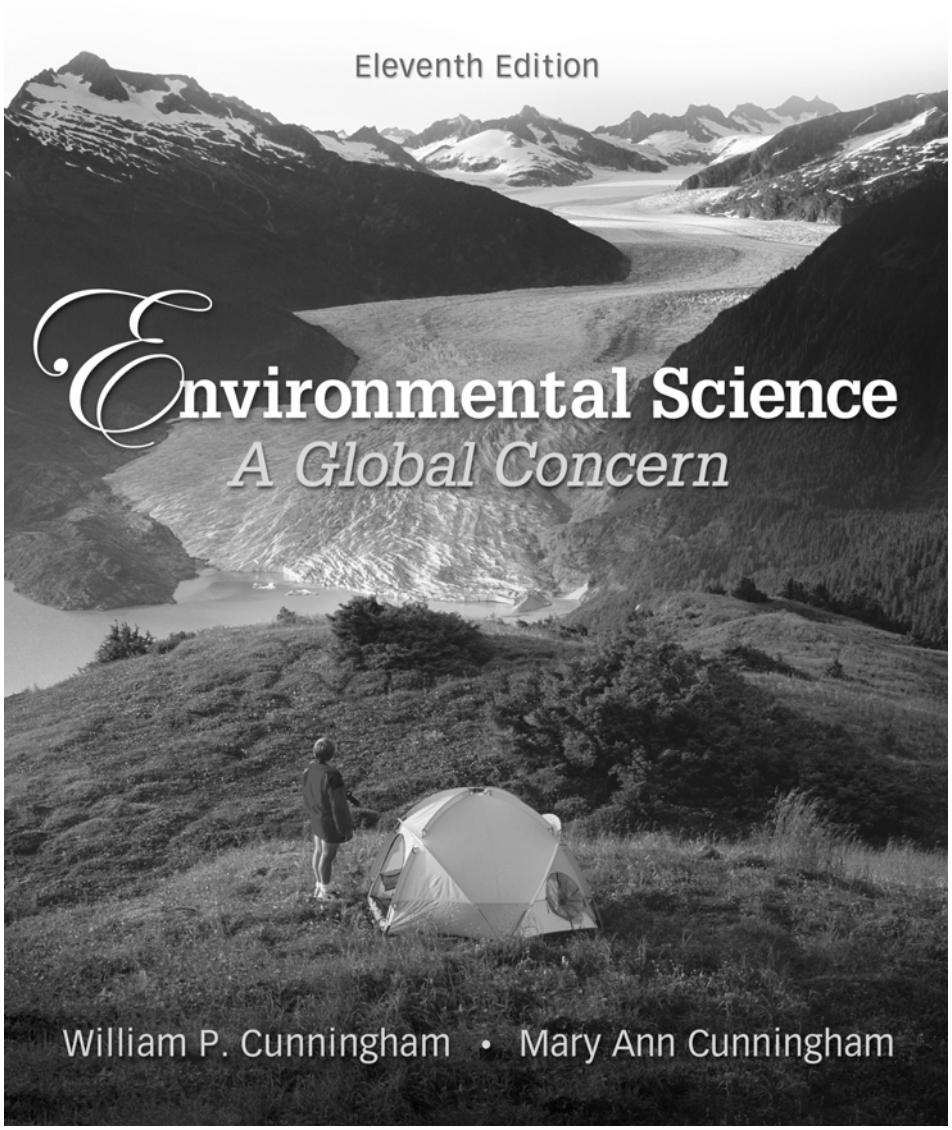

***See PowerPoint Image Slides for all figures and tables pre-inserted into PowerPoint without notes.**

Water Use and Management

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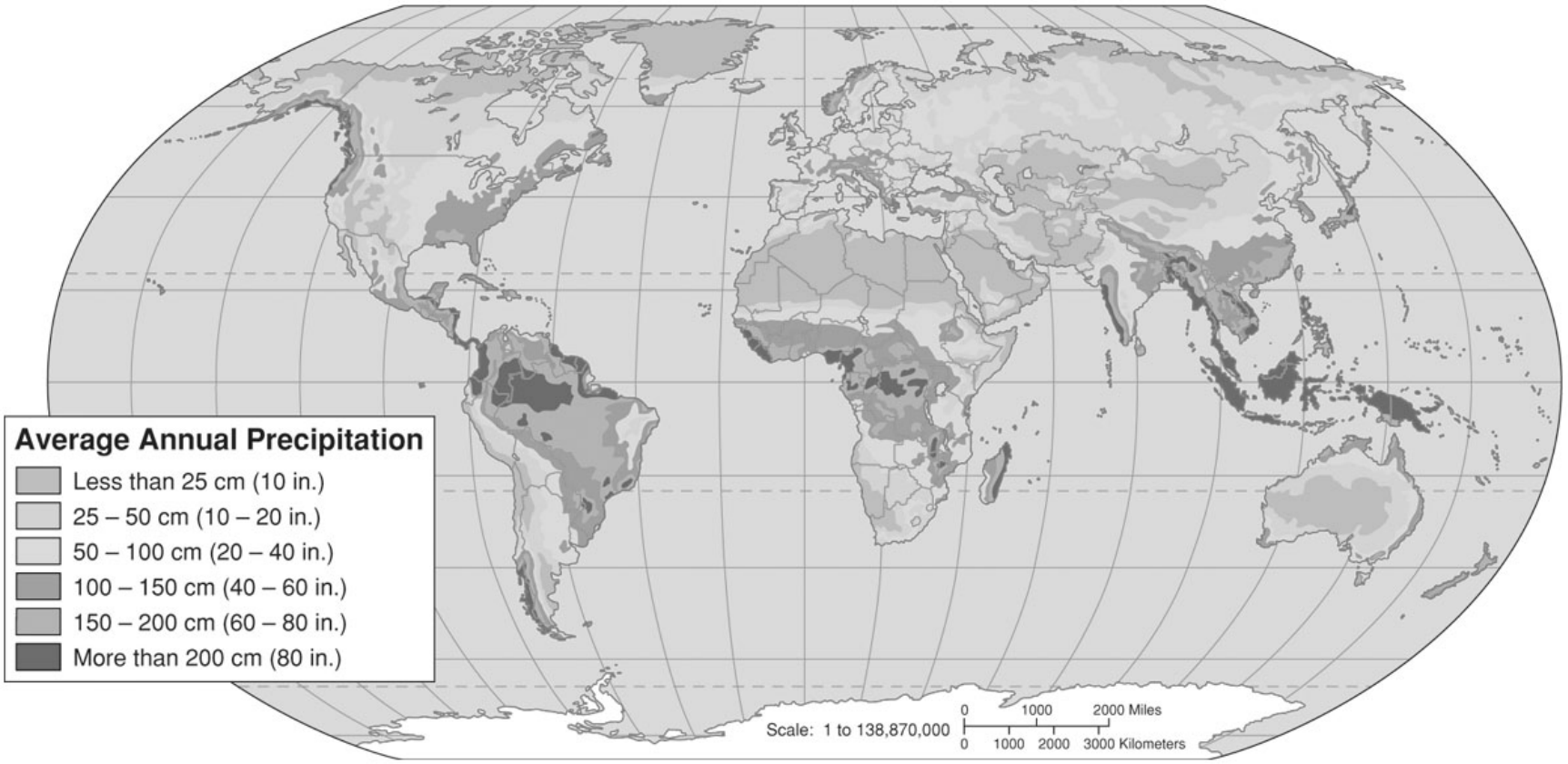
Outline

- Hydrologic Cycle
- Uneven Water Distribution
- Major Water Compartments
- Water Availability and Use
- Droughts and Water Shortages
- Water Use is Increasing
- Groundwater Depletion
- Dams and Diversions
- Fighting Over Water
- Conservation of Water Supplies

The Hydrologic Cycle Redistributes Water

- Hydrologic Cycle —water evaporates from moist surfaces, falls as rain or snow, passes through living organisms and returns to the oceans.
- 500,000 cubic kilometers of water evaporates each year from the world's oceans and enters the cycle.
- >90% of this water rains back into the oceans.
- 47,000 cubic kilometers of this water is carried over land where it renews freshwater systems.
- Plants play a major role in the hydrologic cycle as they pump water from the soil and release it into the atmosphere.
- Solar energy drives the hydrologic cycle.

Average Annual Precipitation



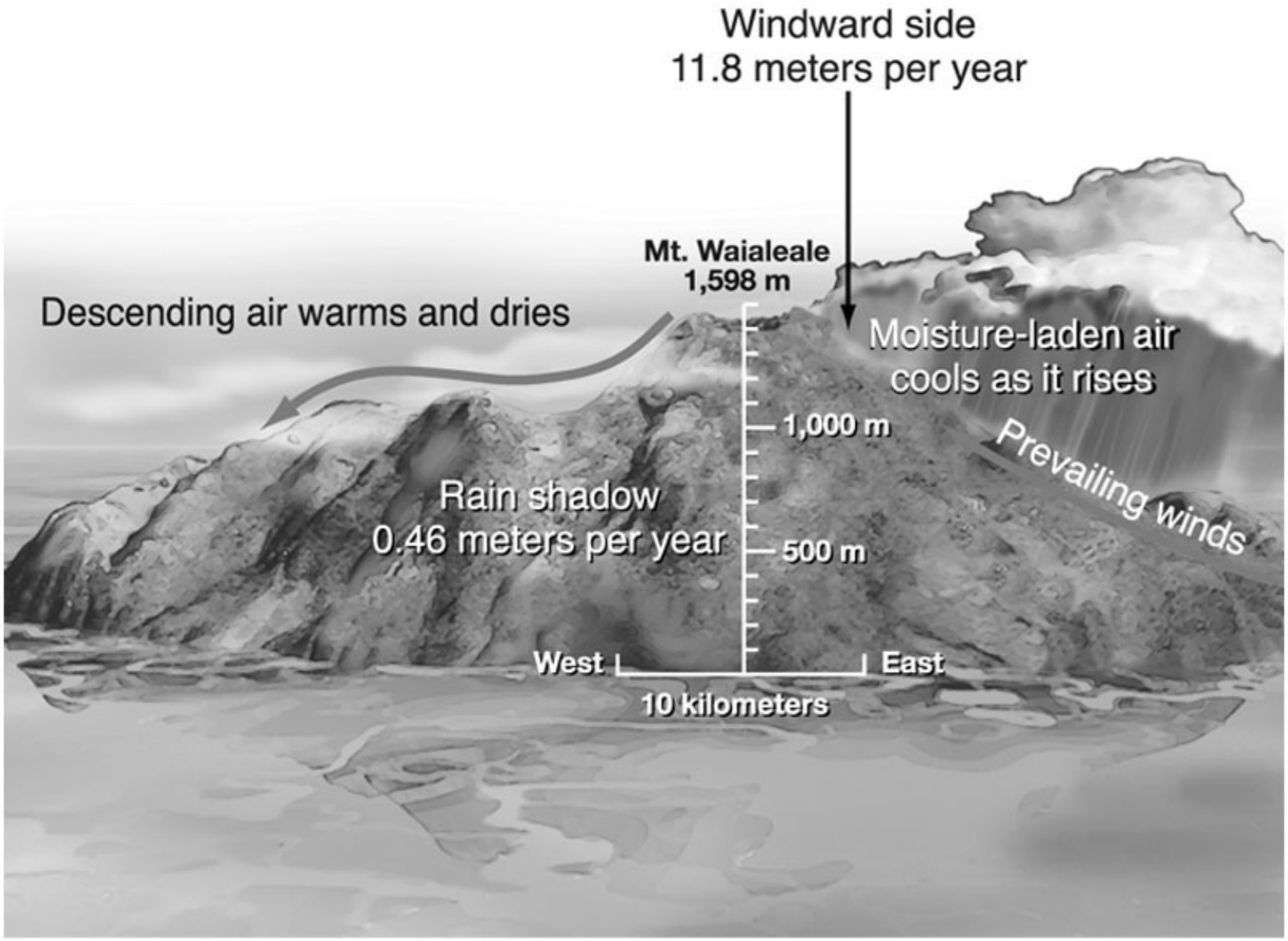
Water Supplies are Unevenly Distributed

- Rain falls unevenly across the earth's surface. Some areas receive practically no precipitation and other areas receive heavy rain on a daily basis.
- Three principal factors control global water deficits and surpluses:
  - Global atmospheric circulation
  - Proximity to water sources
  - Topography

Mountains act as cloud formers & rain catchers

- Air sweeps up the windward side of a mountain, pressure decreases, and the air cools.
  - Eventually saturation point is reached, and moisture in the air condenses.
    - Rain falls on the mountaintop.
    - Rain Shadow --Cool, dry air descends from the mountaintop down the other side of the mountain creating dry areas with very little precipitation.
    - ie. Mount Aialeale in Hawaii rain on east side of mountain is 20 times that on the west side.

Rain Shadow



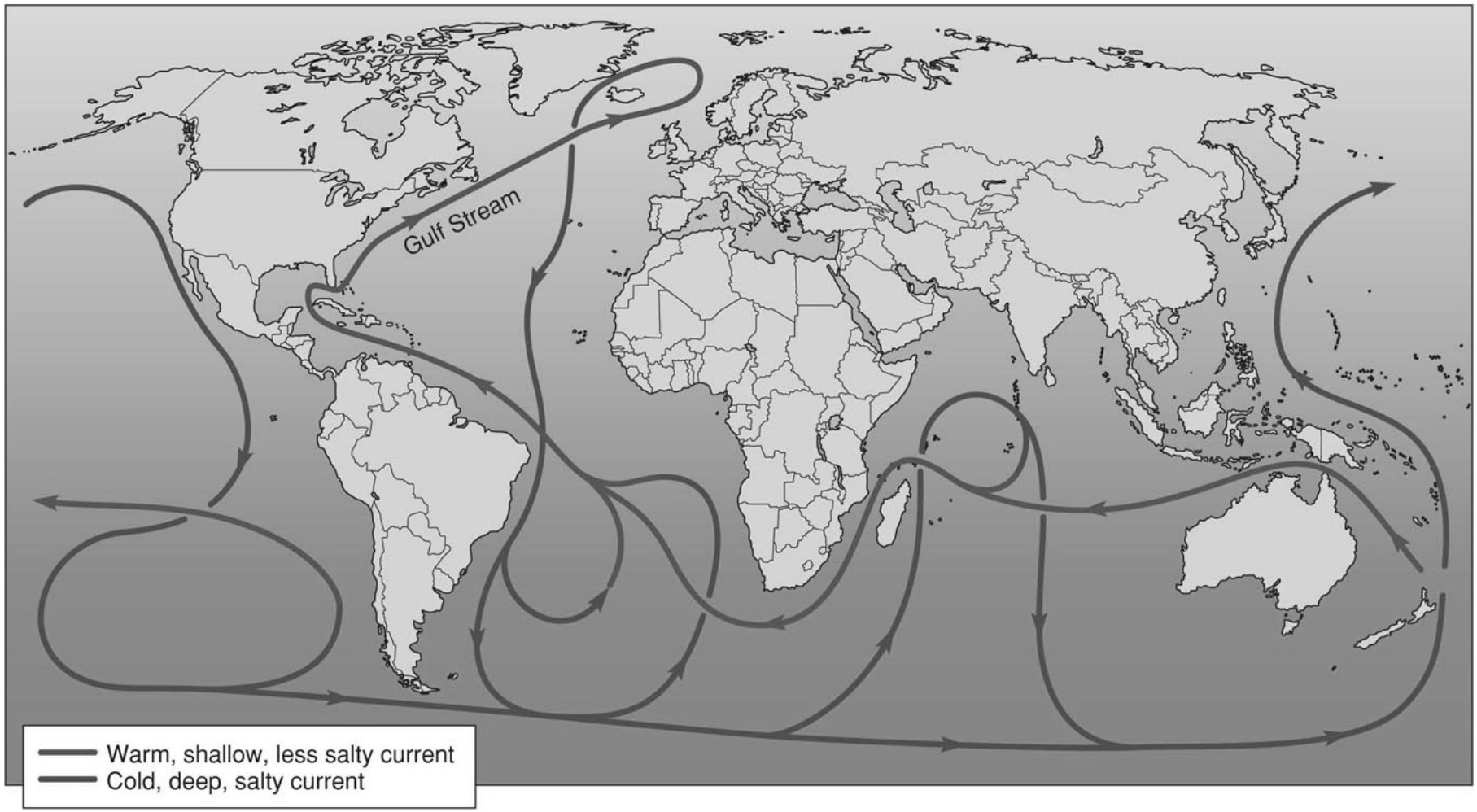
Major Water Compartments

- The distribution of water across the earth is often described as interacting water compartments.
- Water may reside briefly in one compartment of stay there for eons.
- The length of time water typically spends in a compartment is called the Residence Time.
- For example, the Average residence time of water in the ocean is about 3,000 years before the water evaporates and enters the hydrologic cycle.

The Oceans are a Major Water Compartment

- The oceans hold 97% of all liquid water on the earth.
- 90% of the earth's biomass is found in the oceans.
- The oceans play a major role in moderating earth's climate.
- Ocean currents moderate the climate by redistributing warm and cold water around the earth like a global ocean conveyor belt.

Global Ocean Conveyor System



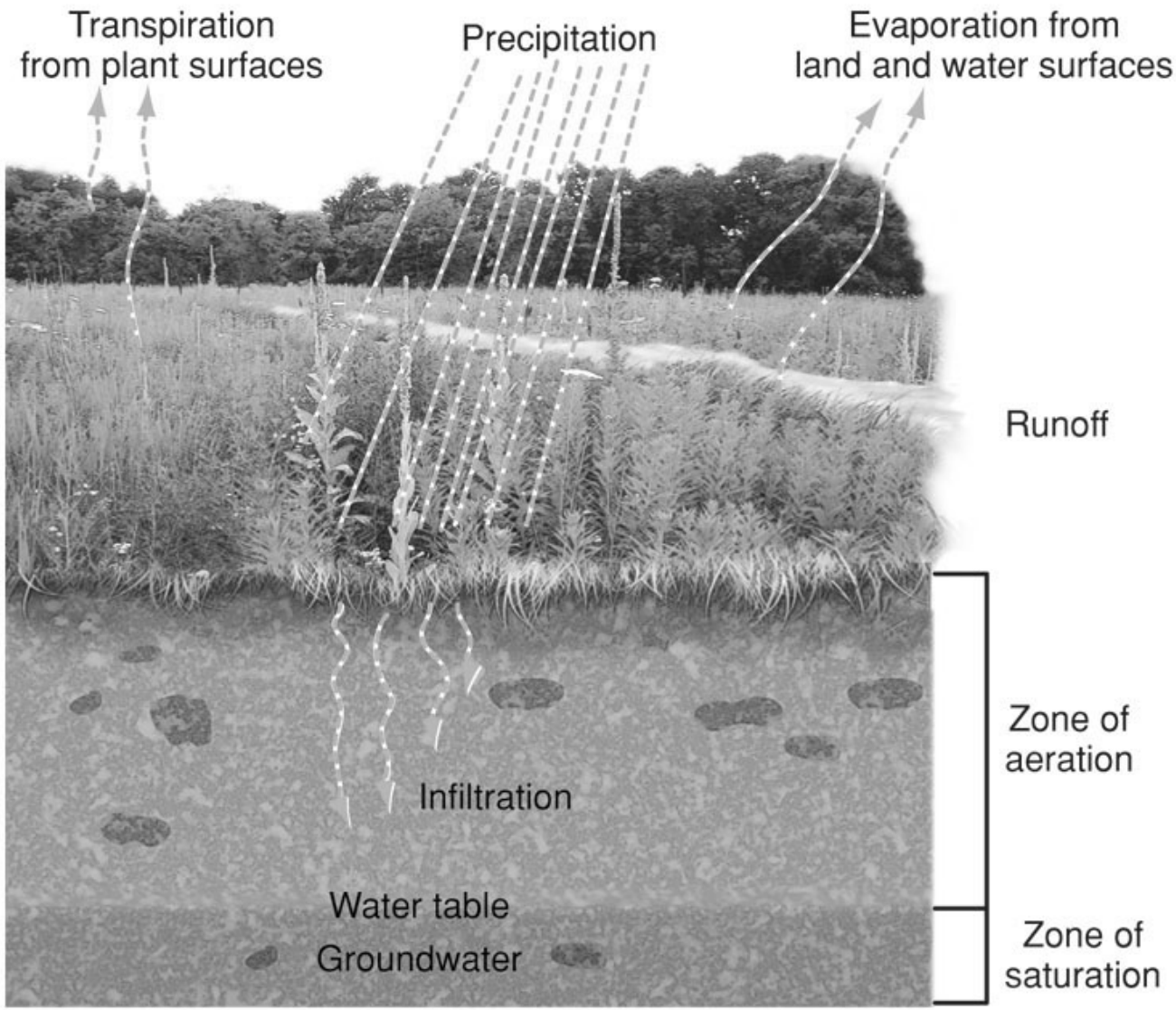
Frozen Water Compartments

- Glaciers, Ice, and Snow
  - 2.4% of world's water is classified as fresh.
    - 90% in glaciers, ice caps, and snowfields
      - As recently as 18,000 years ago, one-third of continental landmass was covered by glacial ice sheets.
        - Now, Antarctic glaciers contain nearly 85% of all ice in the world.
        - Greenland, together with ice floating around the North Pole, is another 10%.

Ground Water Compartments

- Ground water is the second largest reservoir of fresh water
  - Infiltration - process of water percolating through the soil and into fractures and permeable rocks
    - Zone of aeration - upper soil layers that hold both air and water
    - Zone of saturation - lower soil layers where all spaces are filled with water
      - Water table - top of zone of saturation

Infiltration

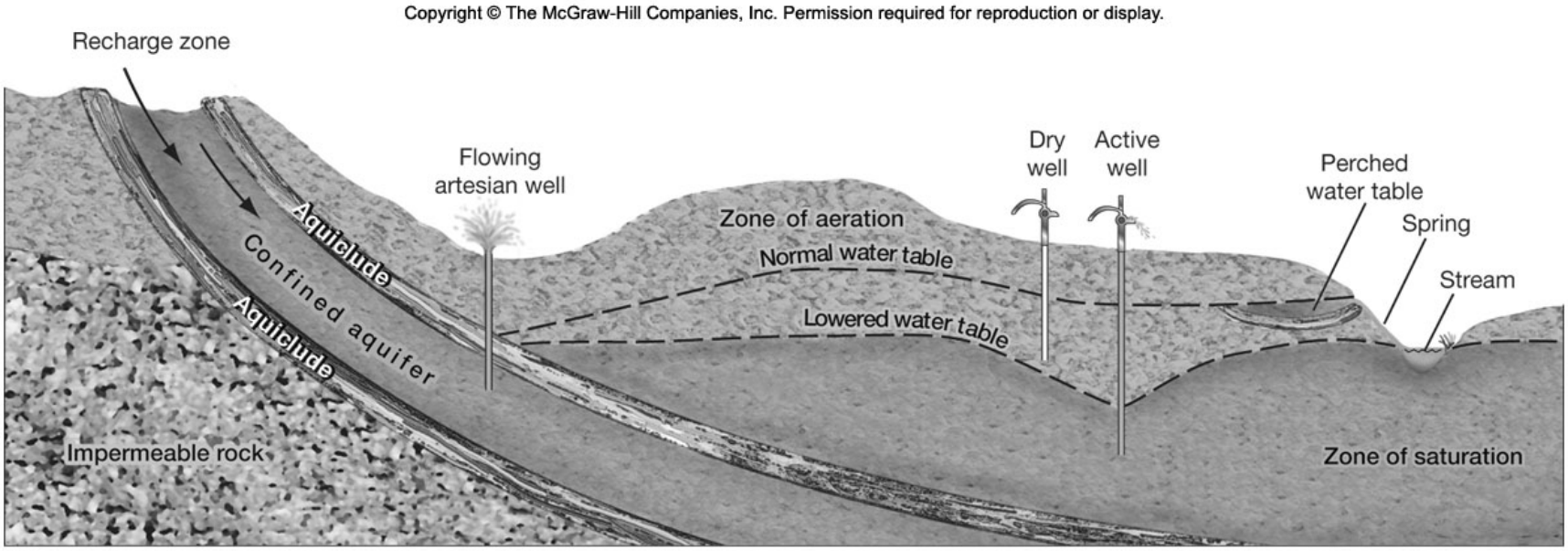


Groundwater Stores Large Water Resources

- Aquifers - porous layers of sand, gravel, or rock lying below the water table
  - Artesian - Pressurized aquifer intersects the surface (water flows without pumping).

- Recharge zones - area where water infiltrates into an aquifer
  - Recharge rate is often very slow.
    - Presently, groundwater is being removed faster than it can be replenished in many areas.

Groundwater



River & Streams Are Water Compartments

- Rivers and Streams
  - Precipitation that does not evaporate or infiltrate into the ground runs off the surface, back toward the sea.
    - Best measure of water volume carried by a river is discharge
      - The amount of water that passes a fixed point in a given amount of time
        - Usually expressed as cubic feet per second

Major Rivers of the World

Table 17.3 Major Rivers of the World

River	Countries in River Basin	Average Annual Discharge at (m^3/sec)
Amazon	Brazil, Peru	175,000
Orinoco	Venezuela, Colombia	45,300
Congo	Congo	39,200
Yangtze	Tibet, China	28,000
Bramaputra	Tibet, India, Bangladesh	19,000
Mississippi	United States	18,400
Mekong	China, Laos, Burma, Thailand, Cambodia, Vietnam	18,300
Parana	Paraguay, Argentina	18,000
Yenisey	Russia	17,200
Lena	Russia	16,000

1 m^3 = 264 gallons.

Source: World Resources Institute.

Lakes and Ponds are Water Compartments

- Lakes and Ponds
  - Ponds are generally considered small bodies of water shallow enough for rooted plants to grow over most of the bottom.
  - Lakes are inland depressions that hold standing fresh water year-round.
    - Both ponds and lakes will eventually fill with sediment, or be emptied by an outlet stream.

Wetlands are Water Compartments

- Wetlands
  - Play a vital role in hydrologic cycle
    - Lush plant growth stabilizes soil and retards surface runoff, allowing more aquifer infiltration.
      - Disturbance reduces natural water-absorbing capacity, resulting in floods and erosion in wet periods, and less water flow the rest of the year.
      - Half of U.S. wetlands are gone.

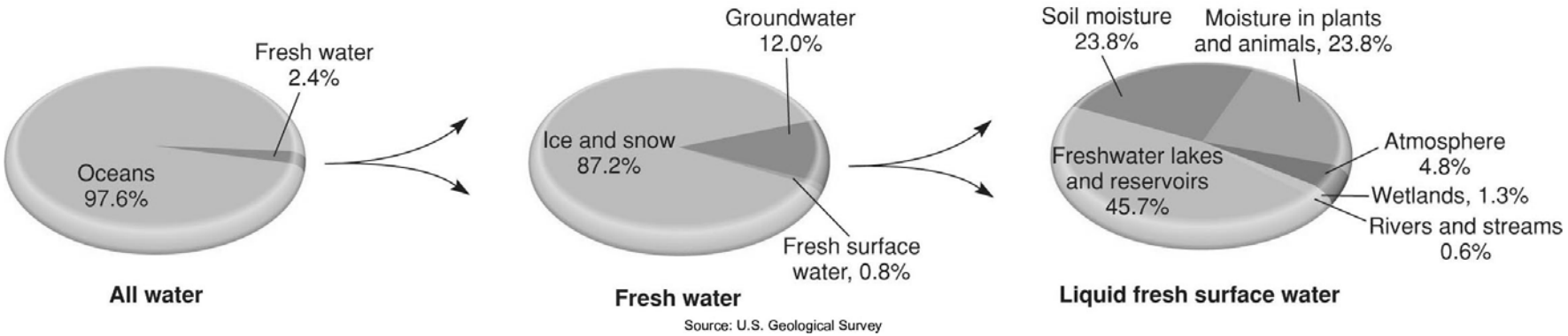
The Atmosphere: A Small Water Compartment

- The Atmosphere
  - Among the smallest water reservoirs
    - Contains < 0.001% of total water supply
    - Has most rapid turnover rate
    - Provides mechanism for distributing fresh water over landmasses and replenishing terrestrial reservoirs

Water Availability and Use

- Renewable Water Supplies
  - Made up of surface runoff plus infiltration into accessible freshwater aquifers
    - About two-thirds of water carried in rivers and streams annually occurs in seasonal floods too large or violent to be stored effectively for human use.
      - Readily accessible, renewable supplies are only about 400,000 gal /person/year.

Easily Available Fresh Water is Scarce



Source: U.S. Geological Survey

Many Countries Suffer Water Scarcity

- Every continent has regions of scarce rainfall due to topographic effects or wind currents.
  - The United Nations considers 264,172 gallons per person per year to be the minimum necessary to meet human needs.
  - Water Stress occurs when human and ecosystem needs outstrip the renewable water supplies.
  - Periodic droughts create severe regional water shortages in semiarid zones where moisture availability is the critical factor in plant and animal distributions.

Drought Cycles

- Droughts are often cyclic.
- In the U.S. the drought cycle is about 30 years.
- The Dust Bowl of the 1930's is a prominent example of a drought period in the Western U.S.
- Much of Western U.S., like the Klamath River Basin, are still plagued by drought and overexploitation of limited water supplies.
- El Nino plays an important role in determining when North America has drought.
- Global warming may make droughts more frequent and severe.

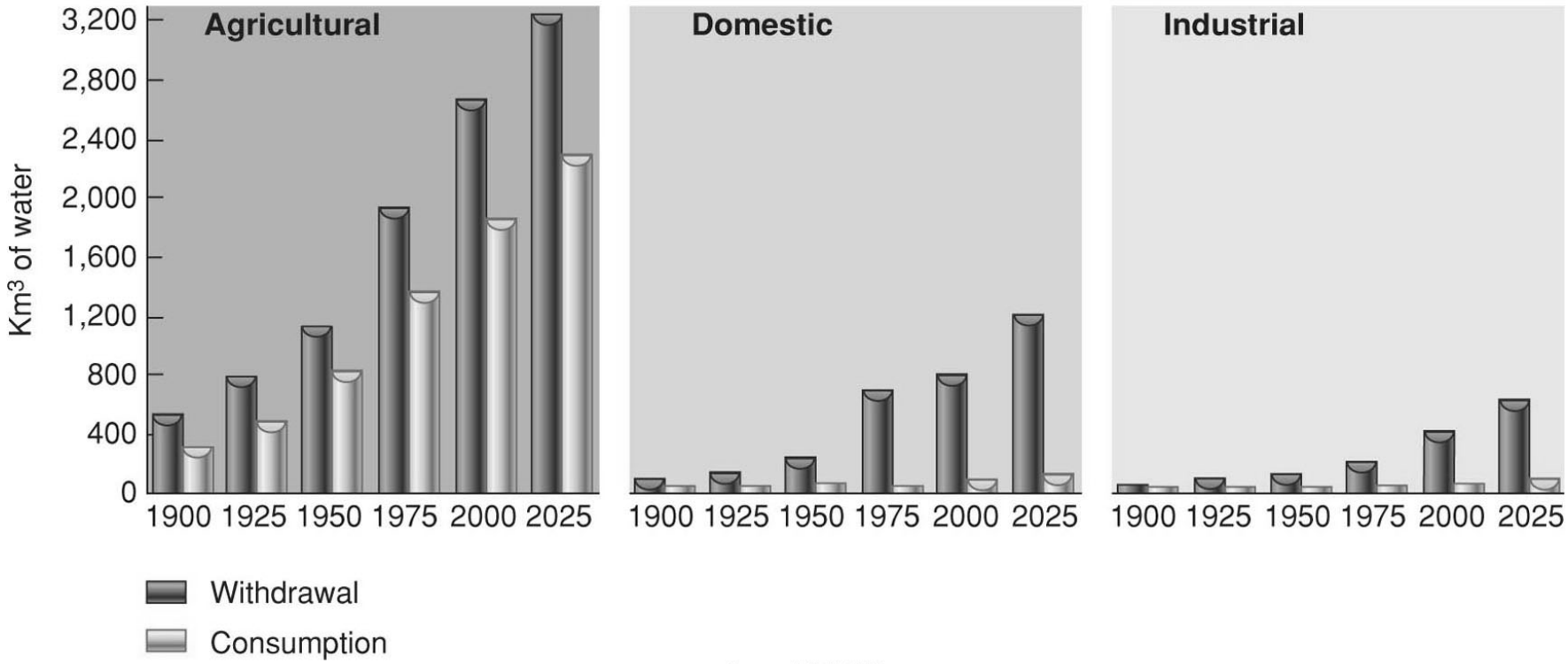
Water Consumption Is Less Than Withdrawal

- Withdrawal - total amount of water taken from a source
- Consumption - fraction of withdrawn water made unavailable for other purposes (not returned to its source)
  - Degradation - Change in water quality due to contamination making it unsuitable for desired use. Much water that is not consumed is nevertheless polluted.

Water Use is Increasing

- Many societies have always treated water as an inexhaustible resource.
  - Natural cleansing and renewing functions of hydrologic cycle do not work properly if systems are overloaded or damaged
  - Renewal of water takes time
  - Rate at which we are now using water makes conservation necessary

Water Withdrawal and Consumption



Source: UNEP, 2002

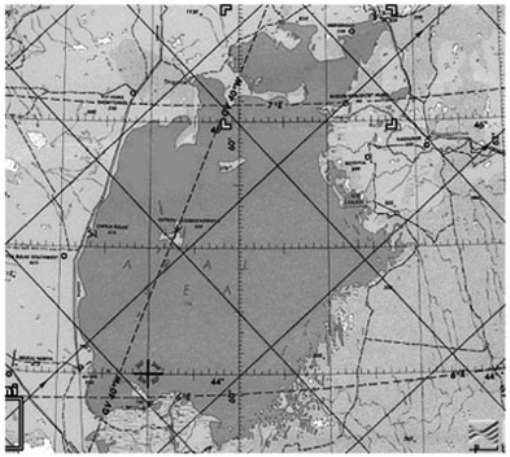
Quantities of Water Used

- Human water use has been increasing about twice as fast as population growth over the past century, but impact varies with location.
  - Canada withdraws less than 1% of its renewable supply per year.
  - In Israel, groundwater and surface water withdrawals equal more than 100% of the renewable supply. Obviously, this is not sustainable.
  - U.S. uses 20% of renewable water/yr.

Agricultural Is the Greatest Water Consumer

- Water use is divided into agriculture, domestic use and industrial use.
- Worldwide, agriculture claims about two-thirds of total water withdrawal and 85% of consumption.
  - Aral Sea, is a tragic example of this.
  - The Aral Sea was once the fourth largest inland body of water in world, but it has now lost 80% of its volume since 1975 as the water was diverted for irrigation of rice and cotton crops.
  - Lake Chad is another example. Located in northern Africa, this lake went from 400,000 sq. km to less than 1,000 sq. km.

Aral Sea



1975

EROS Data Center, USGS

1987

NASA

1997

EROS Data Center, USGS

2005

EROS Data Center, USGS

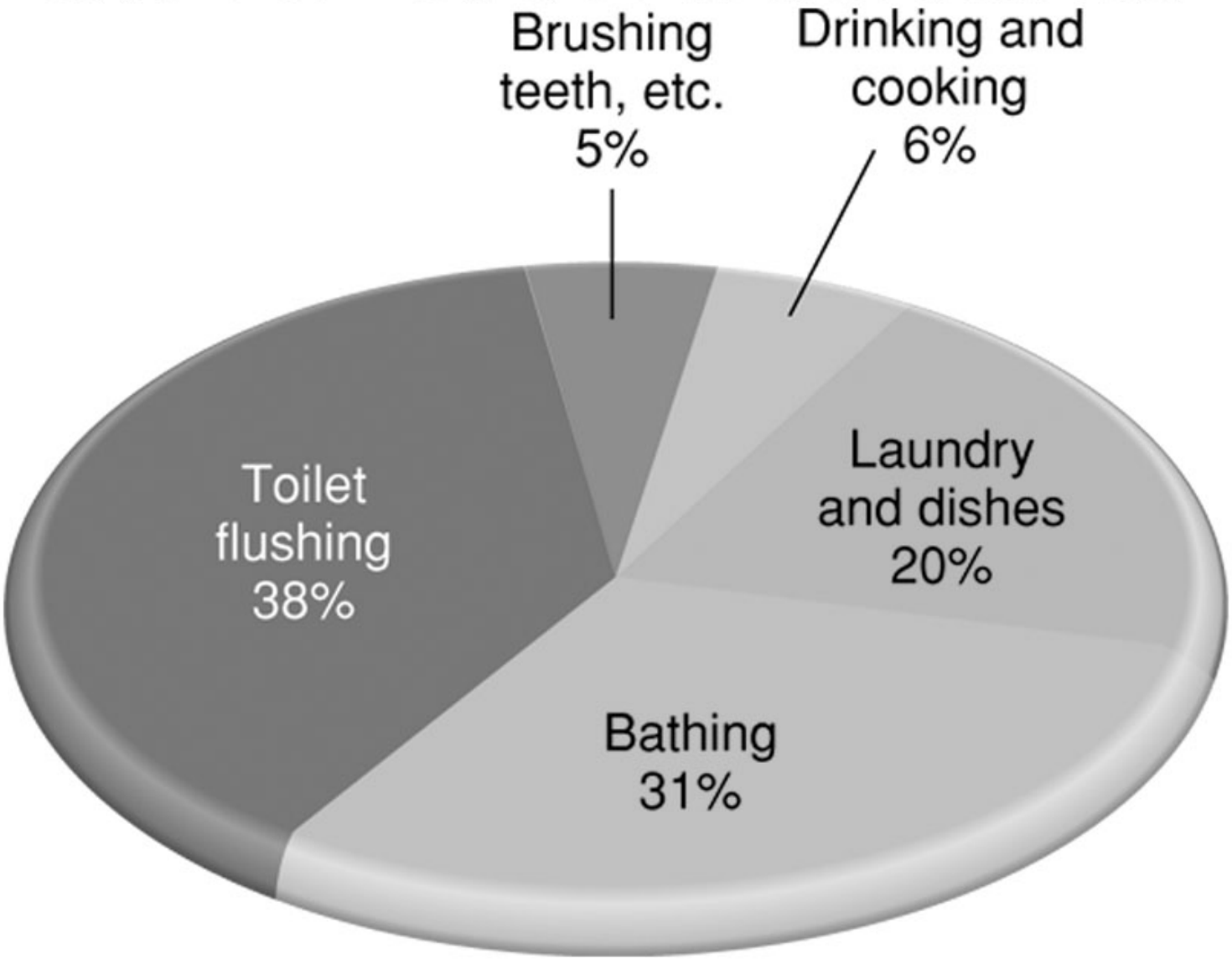
Water Use in Agriculture

- Irrigation can be inefficient.
  - Flood or furrow irrigation
    - Half of water can be lost through evaporation.
    - Flood irrigation used to remove salts from field, but salt contaminates streams
  - Sprinklers have high evaporation.
  - Drip irrigation releases water near roots, conserving water.

Domestic and Industrial Water Use

- Worldwide, domestic water use accounts for about one-fifth of water withdrawals.
  - Only about 10% of consumption
    - But where sewage treatment is unavailable, water is degraded
- Industry accounts for 20% of global freshwater withdrawals.
  - Range from 5% to 70% in various locations
    - Small proportion is consumed, but degradation is a problem

Typical Household Water Use in U.S.



Freshwater Shortages

- U.N. estimates a billion people lack access to safe drinking water.
  - 2.6 billion lack acceptable sanitation.
- At least 50 countries, mostly in Africa and the Middle East, are considered to have serious water stress.
- In many countries it is not access to water that is a problem, it is access to *clean* water that is the problem.

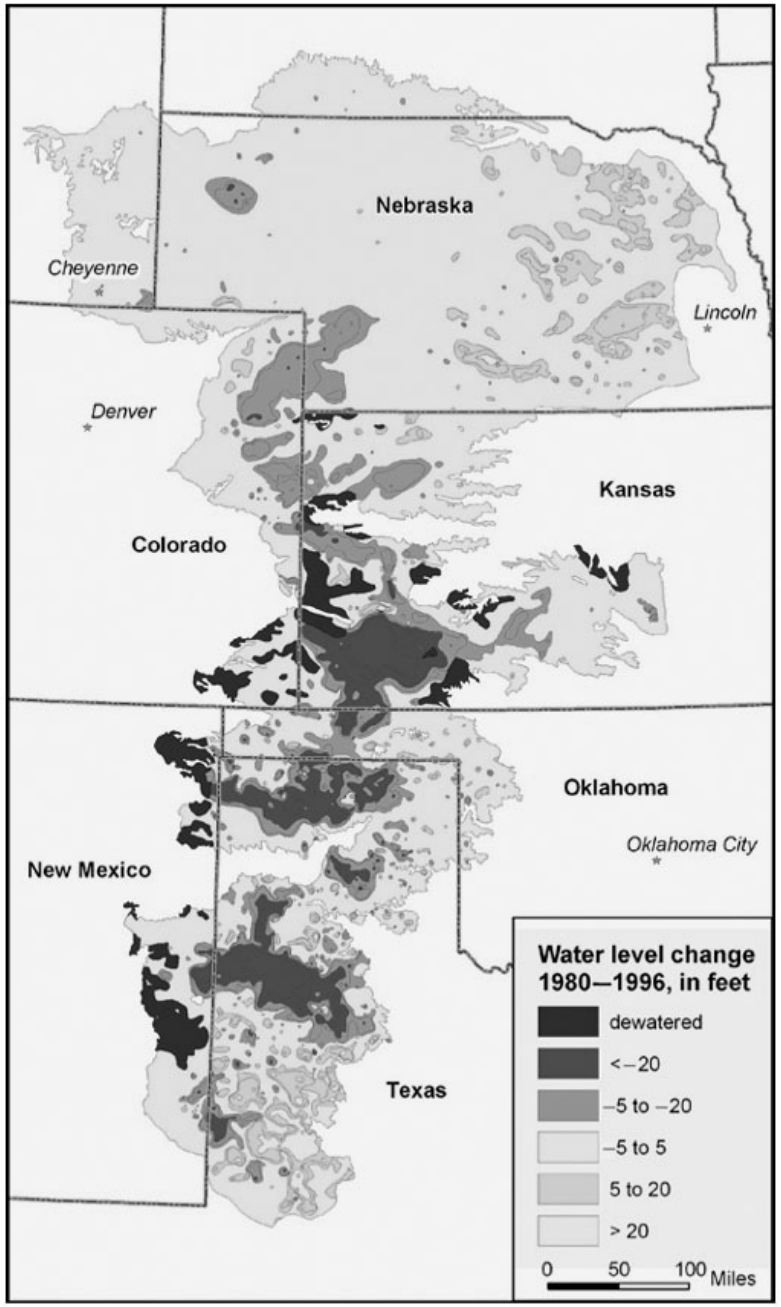
Many People Lack Access to Clean Water

- More the 2/3 of the world's population lack indoor plumbing and must fetch water from outside the home.
- Where water is available in the home, it may be expensive. In Lima Peru, a typical poor family uses 1/6 as much water as a typical middle class family in the US and pays 3 times as much for the water and they must boil the water before it is safe to drink.
- By 2025, the U.N. estimates that 2/3 of the word's population will be living in water stressed countries.

Groundwater is Being Depleted

- Groundwater is the source of nearly 40% of fresh water in the U.S.
- 50% of Americans (95% in rural areas)depend on groundwater for drinking and domestic uses.
  - In many places in the U.S., groundwater is being withdrawn faster than it is replenished leading to a cone of depression in the water table.
  - Heavy pumping can deplete entire aquifers.
    - Ogallala Aquifer underlies 8 states between Texas and North Dakota.
    - Heavy pumping has dried up wells and whole towns are being abandoned
    - It will take thousands of years to refill.

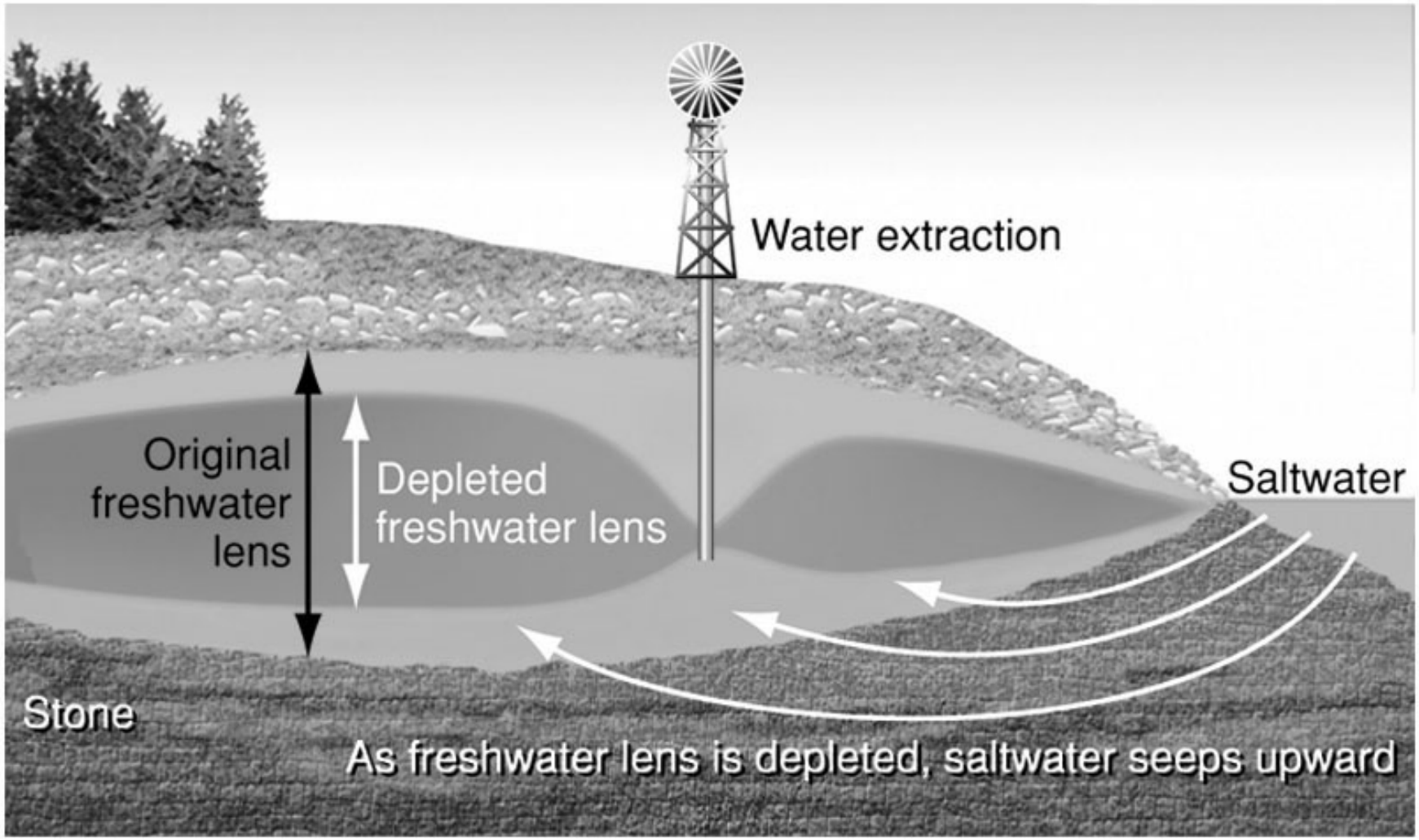
The Ogallala Aquifer



Depleting Groundwater

- Withdrawing large amounts of groundwater in a small area causes porous formations to collapse, resulting in subsidence (settling).
  - Sinkholes form when an underground channel or cavern collapses. Results in permanent loss of aquifer.
  - Saltwater intrusion can occur along coastlines where overuse of freshwater reservoirs draws the water table low enough to allow saltwater to intrude.

Saltwater Intrusion



Climate Change Threatens Water Supplies

- The IPCC warns that climate change together with the developing problems of urban sprawl, population growth and pollution will result in significant water shortages around the world.
- The IPCC predicts that reduced precipitation and increased evaporation from higher temps will result in 10-30% reduction in run-off in arid regions over the next 50 years.

Global Water Shortages

- In many parts of the world, severe droughts are already resulting in depleted rivers, empty reservoirs and water shortages for millions of people.
- South Australia is suffering from droughts, water shortages and wildfires.
- China is facing a massive water crisis.
  - The Gobi Desert is moving eastward and may soon encompass Beijing. Without a new water source, the 15 million inhabitants of this city will have to be relocated.

North American Water Shortages

- North America also faces water shortages due to climate change.
- The U.S. Government projects that 36 states will experience water deficits in the next decade.
- Between 2004 and 2008, the Southeastern U.S. suffered a drought that resulted in water conflicts between Alabama, Georgia and Florida.
- Millions of residents of these states were competing with wildlife, industry and agriculture for the remaining available water.

Dams and Diversions

- Before 1900 there were 250 high dams in the world; today there are more than 45,000.

- In the U.S. dams are built by Army Corps of Engineers and Bureau of Reclamation
  - Provide cheap hydroelectric power
  - Jobs
  - Reduce flooding
  - Allow farming on lands that would otherwise be too dry

Dams and Diversions

- On the downside, dams
  - Drown free flowing rivers
  - Submerge farmlands and towns
  - Block fish migration e.g. salmon
  - Change aquatic habitats for native species
  - Can sometimes fail, causing catastrophe
    - Johnstown flood (city just east of Pittsburgh, PA) killed 2,200 people when dam broke.
    - Dam failure in China killed 230,000.

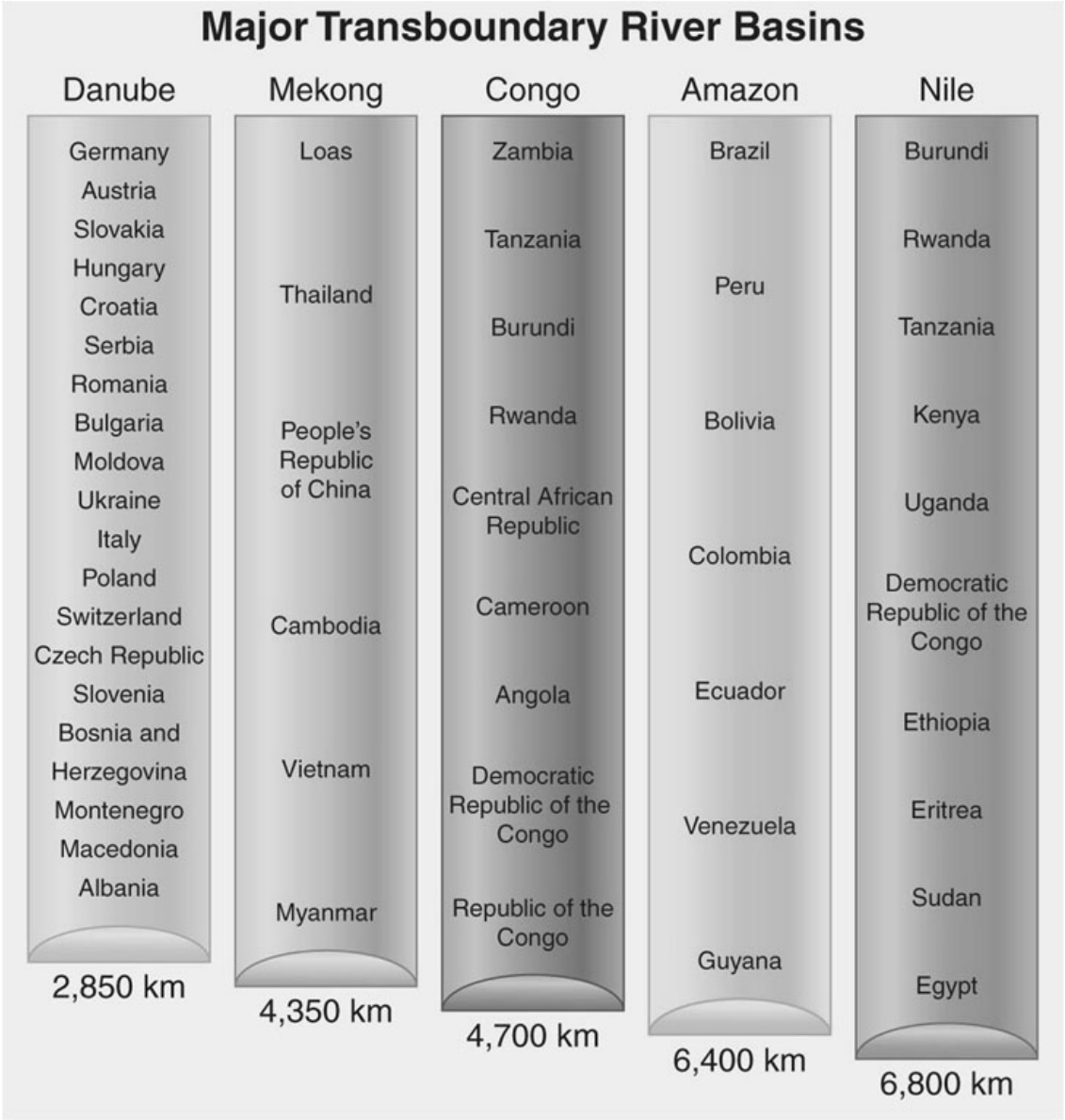
Rivers are Shrinking

- The world's rivers are shrinking as rainfall declines and snowpack melts earlier in the year than normal.
- The Ganges in India, the Yellow River in China, the Indus in Pakistan and the Colorado in the U.S. have all been reduced to a muddy trickle in the lower portions of their river basins.

Would You Fight for Water?

- Many environmental scientist warn that declining water supplies could lead to wars between countries in the future.
- Nearly 40% of the world's population live in river or lake basins that are shared by 2 or more countries.
- There have already been water skirmishes:
  - Israel and its neighbors over the Jordan River.
  - Turkey and Iraq over the Tigris and the Euphrates Rivers.
  - Nomadic tribes in Kenya have fought over dwindling water resources.

Trans-boundary River Basins



Data World Water Day, 2009

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Dams Displace People & Damage Ecosystems

- China's 3 Gorges Dam flooded 1500 towns and displaced 1.4 million people.
- A dam built on India's Narmada River displaced over 1 million people and spurred many protests.
- The Army Corps of Engineers announced in 1998 that it would no longer be building large dams and would be removing some older dams to restore natural habitats.
- Dams are especially lethal for migratory fish such as salmon

Sedimentation Limits Reservoir Life

- Sediment carried by rivers eventually fills up dams
- More than 10 million metric tons of sediment per year collect behind the Glen Canyon and Boulder Dams on the Colorado River.
- Within a century these reservoirs will be filled with sediment and useless for water storage or hydroelectric generation.
- In addition, downriver habitats lose nutrients and the beaches disappear as sediment is no longer available.

Getting By With Less Water

- In Oregon's Klamath River Basin, farmers recently signed a water use agreement where they agreed to reduce water usage by 10-25% and install water conservation measures.
- Land Banking --Some farmers may decide to let some of their land lay fallow in dry years.
- Walking Wetlands --Others farmers may flood fields on a rotational basis to create temporary wetlands.
- These strategies allow for farmers to plan ahead and wetlands birds to have habitat.
- Money designated for endangered species protection will fund these new farming practices

Snow Geese Flying Over Klamath Wetlands

© Photodisc/Getty RF

Increasing Water Supplies

- Seeding Clouds
  - Condensation nuclei
- Desalination - removing salt from ocean water or brackish water to get fresh water
  - Most common methods are distillation and reverse osmosis.
    - Three to four times more expensive than most other sources

Domestic Conservation

- Estimates suggest we could save as much as half of domestic water usage without change in lifestyle
  - Largest domestic use is toilet flushing
    - Can use low volume toilets or waterless composting
    - Anaerobic digesters use bacteria to produce methane gas from waste
  - Significant amounts of water can be reclaimed and recycled.
    - Purified sewage effluent
      - San Diego pumps water from sewage plant directly into drinking reservoir

Water Recycling

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Price Mechanisms and Water Policy

- Through most of U.S. history, water policies have generally worked against conservation.
  - In well-watered eastern states, water policy was based on riparian use rights.
  - In drier western regions where water is often a limiting resource, water law is based primarily on prior appropriation rights.
    - Fosters “Use it or Lose it” policies, where if you conserve you lose your rights to the water

Price Mechanisms and Water Policy

- In most federal reclamation projects, customers were only charged for immediate costs of water delivery.
  - Dam and distribution system costs were subsidized.
  - Underpriced water in some areas amounted to a subsidy of $500,000 per farm per year.
- Growing recognition that water is a precious and finite resource has changed policies and encouraged conservation across the U.S.

Price Mechanisms and Water Policy

- Charging a higher proportion of real costs to users of public water projects has helped encourage conservation.

- Conservation has been successful. U.S. today uses 10% less water than in 1980 but has 37 million more people.